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Sedimentation in the inundation forest flanking the Central Amazonian blackwater stream Rio Tarumã Mirím (Manaus, Amazonas State)

by

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Abstract

An earlier assessment of the litter habitat of the benthic fauna (WALKER 1992) in the inundation forest alongside the river Tarumã Mirím indicated a high rate of fine sediment deposition on the submerged litter. These sediments included sand, clay and organic particles. Sediment quantity appeared to be a function of the duration of the inundation period and as such, of maximum water depth occurring in June. In order to confirm the magnitude of this sedimentation process, sampling was repeated. The method, however, was modified to collect total fine sediment deposition. According to this renewed evaluation, total fine sediment deposition during one year's inundation cycle amounts to circa 1 kg/m^2 (= 10 t/ha) which, depending on sampling area, corresponds to a rate of 1.4-3.0 t/ha x yr x m water depth in June.

Keywords: **Leaf litter, river sediments, inundation forest, Central Amazon, Brazil.**

Resumo

Num estudo anterior (WALKER 1992) foi caracterizado o habitat da fauna bentica, ou seja, a serrapilheira submersa na floresta inundada (igapó) no vale do rio preto Tarumã Mirím. Neste ocasião foram encontradas quantidades consideráveis de sedimentos finos (caulim, quartzo, particulas orgânicas) cobrindo a liteira submersa. A quantidade de sedimentos dependeu do período anual de inundação e assim sendo, da profundidade máxima ocorrendo em junho.

Para confirmar a magnitude do processo de sedimentação, as amostragens foram repetidas. No entanto, o método foi modificado para coletar todo sedimento fino e não somente a parte retida na superfície da liteira. Neste estudo apresentam-se estes novos dados. A quantidade total de sedimentos finos de um ciclo anual de inundação é estimada em cerca de 1 kg/m^2 (= 10 toneladas/ha), correspondendo a uma taxa de sedimentação de 1.4-3.0 t/ha x ano por metro de profundidade, em junho.

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Introduction

The biology of the benthic fauna colonizing the inundation forest (igapó) along the blackwater river Tarumã Mirím has been under investigation for several years (WALKER 1987, 1990). This small river is part of the Rio Negro Basin, and as such, the lower circa 20 km of its valley are subject to the annual inundation by the Rio Negro/Solimões system, with highest water levels in June. From Sept./Oct. to Jan./Feb. the river and its affluent streams are confined to their channels.

Submerged leaf litter is the prevalent habitat of the benthic fauna in the flooded forest. A previous paper (WALKER 1992) describes the magnitude of this habitat, i.e. number of litter leaves per area, and size and dry weight of the leaves. Litter samples were collected from the forest floor at several stations along the river valley, just as the land emerged from the water.

On these occasions I observed considerable quantities of fine sediment deposited on the litter leaves. This sediment was estimated to be circa one ton per hectare and per meter water depth in June, and it consisted of quartz, kaolinite and organic particles. These findings came as a surprize, because Amazonian black waters are transparent and poor in suspended sediments. Hence, further observations were carried out during the inundation period 1990/91. However, the method was modified to collect not only the deposits on the litter leaves, but also the portion of sediment drifting through the litter layer onto the ground. Consequently, one would except larger sediment quantities per inundation period and area.

Lowest water levels ("seca", Oct.-Dec.) in 1990 were exceptionally low, with the bottom of the mouthbay lake ("river-lake", SIOLI 1975) and of its affluent streams largely dry. Hence, some observations on the conditions of the mouthbay river bed are also recorded.

Detailed description of the Tarumã Mirím area, literature references and discussion are provided in WALKER (1992).

Sampling sites and methods

Sampling sites

To avoid misinterpretation of the results, two lateral, and two longitudinal zones must be distinguished.

Laterally, there is the meandering **river bed**, and, adjacent to it, the **forest** of the flat valley bottom. Along the vertical, or even concave, erosion bank of the meanders, which may reach 1.5 m in height, the high-canopy forest grows to the very edge of the river. The inside of the meanders, with low flow speeds or even gentle back flows, is characterized by sand and litter banks, which ascend smoothly and which, depending on water levels, may be up to 15 m wide. On this side of the meander, the high-canopy forest is lined by a succession of seedlings and shrubs.

Longitudinally, there are the upper stream valleys of the headwaters, which are not subject to the annual inundation by the Solimões/Rio Negro system. However, they are irregularly inundated by heavy rains, notably during the rainy season (Dec.-Mai/June). The lower part of the valley is subject to the annual inundation period (Dec.-June: rising water; July-Nov.: falling water). These inundation flows are almost impercetibly slow; from April to July the water is virtually stagnating, and, in the sampling areas, reaches several meters in depth above the forest floor (Tab. 1). In the Manaus area, the annual inundation period coincides largely with the rainy season. Hence, the stagnating water of the lower stream valley receives the input of the high-flow headwaters.

All samples listed in table 1 were taken in the high-canopy forest of the lower valley, remote from the river bed, and refer to one annual inundation period. This holds also for the samples listed in WALKER (1992), if not explicitly mentioned otherwise.

Sampling stations

Station 6 is situated in the middle reach of the Tarumã Mirím valley, under high, closed-canopy forest. A small, meandering first-order blackwater stream joins the Rio Tarumã Mirím at Station 6. The stream and the river are flanked by steep banks ca. 0.7-1.3 m high. The bottom of the channels is of white silicious sand. The samples were taken on the forest floor along a straight line, 5-20 m from the stream bed and 30-80 m from the river bed.

Station 9 lies in the lower valley, at the upper end of the mouthbay lake. The vegetation is relatively open with scattered trees and saplings on clay soils. The samples were taken along a straight line, on the forest floor, some 40-100 m from the vertical river bank of 1-1.5 m height.

Mouthbay lake. In Oct./Nov. 1990, the period of lowest water levels, the bottom of the mouthbay lake and of several affluent streams in this area had become partially desiccated mud flats. The water at the junction with the Rio Negro was only 0.5-1.5 m deep. These exceptional conditions allowed for the observation that the bottom substratum of the Rio Negro in this region, as well as of the mouthbays of the Rio Tarumã Mirím and its affluent streams, is a fine, light-brown mud of clay and organic material. It was impossible to reach Station 9 during this period. The narrow, shallow water course did not allow passage by canoe, nor could we pass the muddy side streams on foot. By mid-December the water had risen ca. 3 m, and was about to enter the forest at Station 9.

Sampling methods

Sediment samples at Stations 6 and 9 were obtained by laying out carpet quadrats on the forest floor. The aim was to collect total sediment for an entire, annual inundation period. Hence, the quadrats (20 x 20 cm^2) were placed when the water was about to flood the area, and they were retrieved within the first 24 to 48 h after the water had receded again (Tab. 1). The quadrats consisted of tightly woven, light brown nylon felt, as used for wall-to-wall carpeting. The carpet squares were sewn into a 5 mm wide aluminium frame with u-shaped cross-section. This secured the edge of the tissue and gave the necessary stability for retrieval and further handling. Before installation, the quadrats were oven-dried and weighed, and identified by numbers scratched on the metal frame. Their weight ranged from 64.18-71.00 g (accuracy of the electronic top-loading METTLER balance ~ ± 0.01 g). In the field the quadrats were placed on level spots of the forest floor, onto the undisturbed layer of litter and debris. Larger obstacles such as depressions, fallen trees and branches, seedlings and roots were avoided. The four corners of the quadrats were fixed by driving a stick into the ground, through a nylon cord loop attached to the corners. The position of the quadrats was indicated by marking nearby trees. Even so, 3 samples were lost at Station 6 and 4 at Station 9. Ten

(10) quadrats were laid out at Station 6 ca. 5 m apart, and 14 at Station 9 some 6 to 15 m apart, depending on the afore-mentioned obstacles.

Quantification of the sediments

Upon retrieval, each quadrat, with everything that had settled on its surface, was placed into a plastic bag which was tightly closed and stored in the refrigerator until processing within the following 7 days. Each sample was processed individually.

Litter leaves and pieces of debris (> 0.2 cm^2) were washed, dried and weighed. The washing water with its sediments was passed through a Melitta filter of pre-determined weight. These paper filters retained all particles ≈ 0.4 µm, as determined by granulometric analysis (A. CHAUVEL, pers. commun.). The filter with its sediment was oven-dried (~ 90 °C) until the weight stabilized. The quadrats with their finer sediments were wrapped in paper and dried until their weight was constant. Paper, loose sediment and the quadrat with its sediment layer were then weighed separately. In this way, total fine sediment per quadrat could be determined by subtracting the weights of the supporting material (carpet quadrat, filter, wrapping paper). The results with the necessary field data are shown in table 1.

In the **mouthbay** of three side streams joining the Rio Tarumã Mirím mouthbay below Station 9, i.e. from the bottom of the stream beds, semi-dry plates of sediments were collected. These conspicuous plates were overlaying a litter layer of relatively intact leaves, which must have been swept into the mouthbay before the sediments settled on their surface, i.e. during the period of litter shedding in 1989 (Sept.-Nov.), while sedimentation occurred during the flooding period from Dec./Jan.-Sept./Oct. 1990. From these plates, which were collected Nov. 01, 1990, I cut blocks of 5 x 5 cm^2. A total of 5 blocks from the three stream mouthbays were dried and weighed.

Results and Comments

Sediment blocks

The data of the five sediment blocks collected on the bottom of the river bed in the mouthbay region were as follows: The block thickness after drying was 4.5 - 6 cm, allowing for some variation within each block of 25 cm^2 surface. The blocks included the litter leaves that were firmly stuck to the bottom, and could not be removed without loosing part of the finer sediment, as well as the finer debris, that was considerably denser in the lower half of the blocks. Mean dry weight per block was 57.16 ± 5.68 g (n = 5).

This corresponds roughly to 22 kg/m^2. This large quantity suggests that part of the more permanent bottom sediment of the river lake was re-suspended during the period of rising and high water (Dec./Jan.-Sept. 1990), and later settled on the litter leaves, when the water was running out of the mouthbay (Oct. 1990). Moreover, during the period of falling waters (Jul.-Oct. 1990), the water flow carried part of the finest sediments of the whole basin to its lowest region, where it settled on the bottom of the river-lake. Accumulation on the bottom of the river-lake is undoubtedly more intense than in the flooded forest of nearby Station 9 (ca. 220 t/ha versus 12.6 t/ha; Tab. 1).

Carpet quadrats

Table 1 summarizes the data on sediment, leaves and debris that were deposited on the carpet quadrats during a single, annual inundation cycle.

When I collected the quadrats at Station 6, I observed that the litter leaves underneath the carpets were extremely brittle and devoid of finer sediments. This indicates firstly, that decomposition of the leaves below the carpets continued, and secondly, that the carpets retained all the sediments that settled on their surface.

Leaf number and weight per area was 20 - 30 % higher than in the former years (1987, 1988), because the previous analysis was confined to the habitat of the litter-dwelling fauna, i.e. to the loosely packed top layer leaves. Accordingly, more sediment was found in 1991 on the leaves in Station 6. The litter layer under the closed canopy at Station 6 collected roughly 50 % of the fine sediments (21.2 g of 42.99 g; Tab. 1); the other half penetrated the litter and settled on the carpet quadrat. The rate of fine sediment deposition in the middle reaches of the Rio Tarumã Mirím was thus much higher than the former estimate of 1 t/ha x yr and per lm of water depth in June (m_{June}), namely 10.75 t: 3.55 m = 3.03 t/ha x yr x m_{June}. This suggests that large quantities of sand and clay are carried downstream from the headwaters during the inundation period, which includes the season of heavy rains (Jan.-June/July), and hence, of intense flow in the upper reaches above the inundation zone. Flood recession, on the other hand, occurs during the dry season (Aug.-Oct.), when headwater flow, and hence, turbulence, are minimal. The sediments on the forest floor are thus not flushed away during the period of falling water levels.

There are no data on suspended sediments for the Rio Tarumã Mirím. Howerver, the limnological conditions of the Rio Uatumã and of its major affluents were monitored between 1978 and 1985, before the construction of the dam of the Balbina hydroelectric power station (RIBEIRO 1985; ELETRONORTE & MONASA/ENGE-RIO 1986). The results of these physico-chemical analyses were typical of Central Amazonian blackwater rivers with black- and clearwater affluents (SCHMIDT 1972). Maximum flow velocity during the rainy season ranged from 0.5 - 1.8 m/sec. In the Rio Tarumã Mirím, flow during several days of heavy rains was ~ 1 m/sec., and suspended sediments are clearly visible during the rainy season (repeated personal observations). In the Uatumã system, the quantity of suspended sediment during the rainy season ranged from 7.2 - 16.2 mg/l for maximum flow; flow velocity of 1.1 m/sec. corresponded to 11.2 mg/l of suspended sediment, i.e. to 11.2 g/m^3 x sec. discharge. Assuming similar orders of magnitude for the Rio Tarumã Mirím with ca. 7 m^2 channel cross-section in its upper course, this would mean 6 - 7 tons of sediments transported per day. Flooding of the headwater stream valleys at high flow velocities during periods of maximum precipitation would further increase the transport of suspended matter. Such conditions might explain the sediment quantities found in the lower valley (Stations 6 and 9; 10 - 12 t/ha x yr; Tab. 1).

These large sediment quantities are, nevertheless, thinly spread over the forest floor. Assuming that volume/weight of loose, fine sediment (which contains a considerable amount of air, as a bag full of sugar for instance), is ≤ 1 cm^3/g, the 21.2 g retained on the litter leaves at Station 6 on the quadrats of 400 cm^2 result in a layer of ≤ 0.5 mm thickness. This agrees with my repeated observations of a thin, whitish surface film covering the litter leaves after emersion, provided one arrives on the scene before the first rain after the recession of the flood.

Leaves plus litter debris in 1991 amounted to 5.69 t/ha at Station 6, and is thus within the range of annual litter production in the area, namely 5 - 7 t/ha (ADIS et al. 1979). As the area is inundated for circa 7 months only (Feb.-Sept.; Tab. 1, which corresponds to the period of collection), while litter shedding occurs over the whole year, notably during the dry months Sept.-Nov., it may be concluded that part of the litter found on the quadrats was swept into the igapó by the headwaters.

At Station 9, litter plus debris deposition was 0.51 t/ha. This relatively small quantity reflects the sparser, open vegetation and suggests, that negligible litter and debris quantities are transported from up-river into the igapó of the mouthbay region. The rate of fine sediment deposition was much lower than at Station 6, namely 1.415 t/ha x yr x m_{June} (= 12.6 t : 8.9 m; Tab. 1). Thus, more of the heavier sediments, such as sands, probably settle in the upper regions of the inundation forest (Station 6).

Taking differences of method into account, the data in Table 1 confirm the earlier findings (WALKER 1992). Extrapolation over larger areas, however, will need further limnological investigation. The general conclusion to be drawn is, that sedimentation processes in Amazonian blackwater basins deserve more attention than they have hitherto attracted.

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Table 1: Sedimentation in the inundation forest at Station 6 (upper region under closed-canopy forest) and at Station 9 (mouthbay region under more open vegetation). Q = quadrat samples of 400 cm^2. Dry weights (g/Q) are extrapolated to tons per hectare (t/ha), and comparative figures of the former (1987, 1988) collections (WALKER 1992) are given for t/ha and leaf number per quadrat (Nrs/Q).
*Water depth in June represents the annual maximum.

Site; n = Nr Quadrats Exposure period Water depth June*		Station 6; n = 7 Quadrats 29. Jan. 1991 - 11. Sept. 1991 ~ 3.4 - 3.7 m			Station 9; n = 10 Quadrats 10. Dec. 1990 - 9. Oct. 1991 ~ 8.5 - 9.3 m		
Substrates		x ± s Range	t/ha	(1987/88)	x ± s Range	t/ha	(1987/88)
Leaves	Nrs/Q	44.6 ± 16.8 11 - 71		(31.8/Q)	12.2 ± 9.0 0 - 26		(16.4/Q)
Leaves	g/Q	16.89 ± 7.51 3.45 - 31.25	4.22	(3.75 t/ha) (n = 14)	1.3 ± 1.34 0 - 3.82	0.32	(0.6 t/ha) (n = 10)
Debris	g/Q	5.88 ± 2.42 2.51 - 9.48	1.47		0.77 ± 0.57 0.11 - 1.61	0.19	
Fine sediment, on leaves only:	g/Q	21.20 ± 8.80 8.87 - 33.72	5.30	(3.86 t/ha) (n = 14)	4.49 ± 4.78 0 - 15.22	1.12	
Total fine sediment	g/Q	42.99 ± 19.59 19.94 - 72.85	10.75		50.41 ± 30.07 9.32 - 102.33	12.60	(> 10 t/ha)